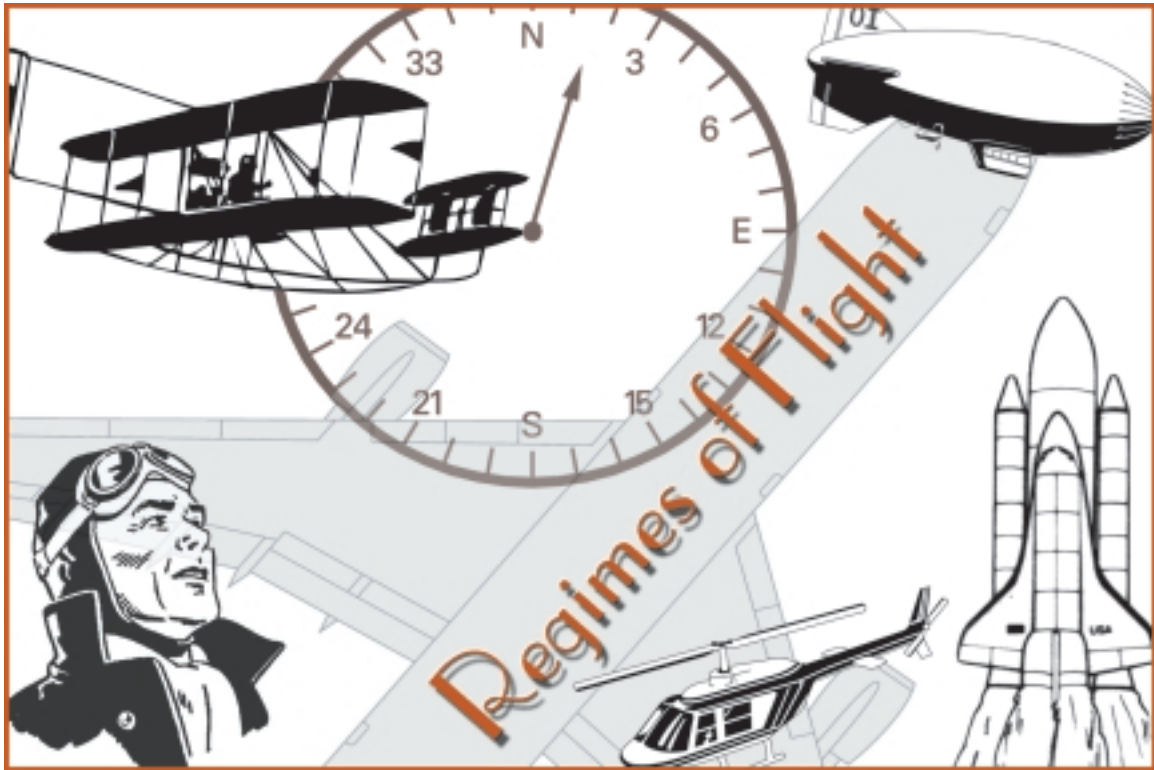


# Regimes of Flight

## A Supplemental Aeronautics Guide



*produced by*



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## Overview

The Web site **Regimes of Flight** is designed for use as additional aeronautical information for students in grades 5-8. The accompanying print material found in this PDF file is intended as supplemental classroom material for enrichment in the physical science of aeronautics.

The print materials contained herein include the following:

- informational readings
- hands-on activities
- writing experiences
- aeronautically-themed mathematics activities
- aeronautical research projects
- mini-literature unit for the online picture book: [A New Regime](#)

All the materials are correlated to the National Science Standards and are cross-curricular. Used in conjunction with the NASA Quest Web site from Aerospace Design Team Online, this print material will provide excellent supplemental material support for your classroom.



# Goals and Objectives

## **Goal 1**

To use the Scientific Method to answer a question or solve a problem.

### **Objectives**

The Learner will be able to:

- recite the steps of the scientific method;
- develop each part of the scientific method:
  - identify a question,
  - identify a hypothesis,
  - construct an experiment;
- list procedures which will complete the experiment:
  - list materials needed to perform experiment,
  - perform experiment;
- record results of experiment:
  - write a conclusion;
- observe and record the observations;
- identify a new question generated by the experiment.

## **Goal 2**

To understand that there are different types of aircraft which have been designed to fly for specific purposes and in specific ways.

### **Objectives**

The Learner will be able to:

- identify and describe the different regimes in which aircraft fly;
- compare aircraft types based upon their flight characteristics.



## Goals and Objectives – *continued*

### **Goal 3**

To understand the speed of sound and its effects on aircraft.

### **Objectives**

The Learner will be able to:

- define the speed of sound;
- describe the phenomenon of flight at the speed of sound;
- identify and describe how sound travels in waves.



## **Correlation to the National Science Education Content Standards**

### **Unifying Concepts and Processes**

- Systems, order and organization
- Evidence, models and explanation
- Form and Function

### **Content Standard A**

Students should develop abilities necessary to do scientific inquiry.

- Identify questions that can be answered through scientific investigations.

Students should design and conduct a scientific investigation.

- Use appropriate tools and techniques to gather, analyze, and interpret data.
- Develop descriptions, explanations, predictions, and models using evidence.
- Think critically and logically to make the relationships between evidence and explanations.
- Recognize and analyze alternative explanations and predictions.
- Communicate scientific procedures and explanations.

Students should develop understandings about scientific inquiry.

- Current scientific knowledge and understanding guide scientific investigations.
- Technology used to gather data enhances accuracy and allows scientists to analyze and quantify results of investigation.
- Scientific explanations emphasize evidence, have logically consistent arguments, and use scientific principles, models, and theories.
- Scientific investigations sometimes result in new ideas and phenomena for study...

### **Content Standard B: Physical Science**

All students should develop an understanding of motions and forces.

- The motion of an object can be described by its position, direction of motion, and speed.
- An object that is not being subjected to a force will continue to move at a constant speed and in a straight line.
- If more than one force acts on an object along a straight line, then the forces will reinforce or cancel one another, depending on their direction and magnitude. Unbalanced forces will cause changes in the speed or direction of an object's motion.

## **Content Standard E: Science and Technology**

All students should develop understandings about science and technology.

- Science and technology are reciprocal.
- Perfectly designed solutions do not exist.
- Technological designs have restraints.
- Technological solutions have intended benefits and unintended consequences. Some consequences can be predicted, others cannot.

## **Content Standard F: Science in Personal and Social Perspectives**

All students should develop an understanding of science and technology in society.

- Science influences society through its knowledge and world view.
- Societal challenges often inspire questions for scientific research....
- Technology influences society through its products and processes.
- Scientists and engineers work in many different settings....

## **Content Standard G: History and Nature of Science**

All students should develop understanding of science as a human endeavor.

- Women and men of various social and ethnic backgrounds...engage in the activities of science, engineering.... Some scientists work in teams, and some work alone, but all communicate extensively with others.
- Science requires different abilities, depending on such factors as the field of study and type of inquiry.

All students should develop understanding of the Nature of Science.

- Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models.
- It is part of scientific inquiry to evaluate the results of scientific investigations, experiments, observations, theoretical models, and the explanations proposed by other scientists.

## Teacher Informational Reading

### Regimes of Flight

Aircraft can be grouped by the range of speed in which they are designed to operate. Aircraft speed has improved with time; consequently, our discussion of aircraft speed will also follow the development of aircraft over time. The “Aircraft Speedline” is divided into five speed ranges, called regimes. Each section below discusses the speed range, design issues, and types of aircraft for these speed regimes, as well as the characteristics that limit the speed in each category.

#### Low Speed Flight: 0-100 MPH (subsonic)

The early development of human flight includes air vehicles in this speed range. The first air vehicles included kites, balloons, and gliders. These unpowered aircraft were very slow. The development of relatively lightweight engines paved the way for early airships and winged aircraft, but the materials, knowledge and technology available limited these aircraft to low speeds.

These vehicles had to be very lightweight because of the limited power of the available engines. To build lightweight structures, designers used external bracing. That, and the open fuselage designs of the day, resulted in vehicles with high drag. So the limited thrust available was overcome by the drag produced even at speeds as low as 50 mph. The most famous example is the 1903 Wright Flyer.

Modern vehicles in this category include kites, balloons, hang gliders, ultra-light hobby aircraft, and airships. As in the early days, these aircraft are limited by the power available from small, light engines and by lightweight structures. These aircraft are generally faster than their predecessors because of stronger, light-weight materials (nylon and aluminum), improved knowledge of aircraft design, and improved engines (with a higher ratio of power to weight).



## Medium Speed Flight: 100-350 MPH (subsonic)

In order to build faster aircraft, several areas or technologies had to be improved. First, the drag had to be reduced substantially. This was accomplished largely by developing enclosed, streamlined fuselages and stronger wings that did not require external bracing. This meant the structure had to be made stronger, but hopefully not heavier. Thus, materials and structures were developed with a higher ratio of strength to weight. Next, the thrust had to be greatly increased without making engines too heavy. Thus, the engine's ratio of power to weight increased. All of these areas improved in a leapfrog manner. For example, a new engine might be developed with 50 percent more power (good!) that weighed 25 percent more (not so good!) Note that this engine has a higher power-to-weight ratio, but it also weighs more. To carry this extra weight, the fuselage would have to be stronger and heavier. The resulting aircraft might not really be faster until it could be designed to be lighter. Finally, our knowledge of aerodynamics improved through the use of new tools such as wind tunnels and a lot of basic research.

The vehicles that are found in this regime are limited by the source of the thrust and, to a lesser extent, the drag. The engines are almost all propeller types, and the wings are almost all straight and fairly thick. Vehicles in this category are propeller craft like Fokker, Junkers, Cessna and Beechcraft. The need for higher-performance aircraft during WWII accelerated the development of aircraft in this speed regime. At the same time that speed was being improved, so was the carrying capacity of aircraft.



## High Speed Flight: 350-760 MPH (subsonic)

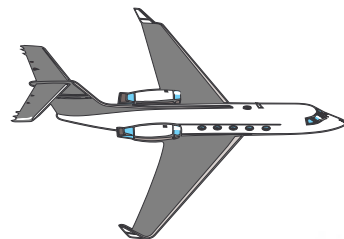
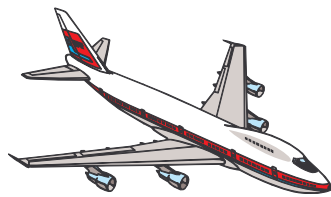
In order to go faster, aircraft needed engines with even higher performance (power/weight). The development of the jet engine was the first key to faster aircraft. As aircraft exceeded 500 mph, the drag increased rapidly, and a new aircraft design was needed to reduce the drag. The development of the thin, sweepback wing provided the second key to high speed flight. As before, improvements in aerodynamic knowledge and technologies such as materials contributed to the evolution of modern, high-speed aircraft.



The resulting vehicles were limited by the power of their engines and the amount of drag they made. Generally, the more swept the wings, the faster they could go. They were all sleek-looking shapes that minimized drag as much as possible. Aircraft were approaching the speed of sound, and drag was increasing dramatically. The speed of sound is about 760 mph at sea level and about 650 mph at 35,000 feet, and is called Mach 1 (for one times the speed of sound). At these speeds, the air has difficulty “flowing” around the airplane, with the result that shock waves form and drag increases dramatically. Also, the aircraft was difficult to control at these speeds. This largely limited aircraft to flying below the speed of sound, called subsonic flight. There are no airplanes that spend significant time flying between 700 and 800 mph because of the high drag and the control issues.

Modern airplanes that fly slower than the speed of sound (fast, but still subsonic) all peak out in speed well short of the speed of sound (below Mach  $<0.9$ ). Higher speed flight would be desirable, but today the best tradeoff between speed and economy for transporting a large number of passengers or cargo is near Mach 0.8. Vehicles in this class are the commercial Boeing 700 series, the Boeing B-47 Strato Jet, Vickers Viscount, the Lear Jet, and many military aircraft.

**Speed of Sound:** The actual speed of sound depends on the compressibility and density of the air as well as its temperature. This means that an airplane flying at the speed of sound at ground level under normal atmospheric conditions will actually be flying at a speed of 760 mph. However, while flying at the speed of sound at 37,000 feet at normal stratosphere temperature, the airplane would actually be flying about 660 mph. If an airplane is flying slower than the speed of sound we say it is moving at subsonic speed. If it is flying at the speed of sound it is traveling at sonic speed. If it is flying faster than the speed of sound we say it is traveling at supersonic speed. When we refer to the speed of sound we measure it in Mach numbers. If an airplane is traveling at Mach 1 it is moving at sonic speed or at the speed of sound. If it is traveling at Mach 2 it is moving at two times the speed of sound. The word “Mach” comes from the Austrian scientist Ernst Mach who studied airflow and the speed at which sound travels.

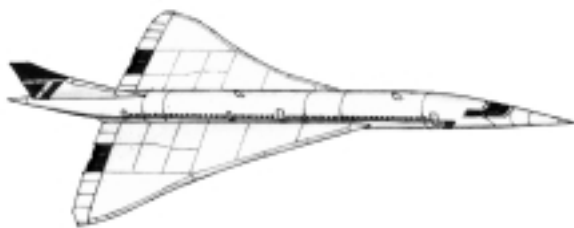


## Supersonic Flight: 760-3,500 MPH (Mach 1 to Mach 5)

With the desire to fly faster, primarily for military aircraft, aeronautics technologies were developed to fly efficiently above Mach 1. Efficiency is a relative term—the aircraft are still very expensive to operate and most are for military use. To date, only one aircraft, the Concorde, provides commercial transportation above Mach 1. Efforts are underway to develop new technologies so that a more cost-effective supersonic airplane can be built in the future.

Supersonic aircraft have special high-performance jet engines that can make a lot of thrust, very thin wings that have lots of sweep, and use novel materials to provide strength. Early fuselages tended to be shaped like a wasp's body (thin at the waist). The thinning of the fuselage helps reduce the drag that the airplane makes when flying near the speed of sound. It is relatively easier to fly above Mach 1 than near Mach 1. Hefty engines are needed to provide the thrust necessary to push the airplane through the air at such high speeds. The wings are super thin and swept to slice through the air while making as little disturbance as possible. The most modern supersonic aircraft spend so little time near Mach 1 and have such powerful engines, that they are not shaped as much like a wasp's body. Still, these aircraft have sleek overall shapes that are carefully designed to minimize supersonic drag.

It is interesting that airplanes designed to fly supersonically do not fly very well at subsonic speeds. The same features that let them fly fast do not work well when flying slowly. In fact, flight at the lowest speeds—takeoff and landing—is an extra challenge when designing these aircraft. Vehicles in this category include the commercial airliner Concorde, F-15 Eagle and the SR-71.



## Hypersonic Flight: 3,500-7,000 MPH (Mach 5 to Mach 10)

With the advent of rocketry, the first hypersonic vehicles were developed. Although they are not airplanes, rockets travel at these speeds as they accelerate into Earth orbit. Also, re-entry capsules such as those in the Apollo program travel at these speeds as they descend from orbit.

Once again, new technologies and new vehicle shapes had to be developed for hypersonic flight. In particular, new materials had to be developed to handle the intense heating caused by atmospheric friction.

The best known examples of hypersonic flight vehicles are the rocket-powered X-15 and the space shuttle which flies through all of the speed regimes when it re-enters the Earth's atmosphere. The space shuttle is coasting from a very high speed and high altitude when it flies hypersonically. It is decelerating the entire time. There are no aircraft today that can cruise at these speeds.

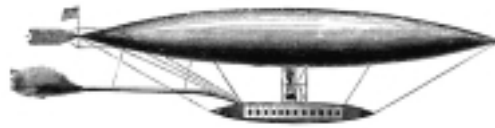
Research programs are underway to develop new engines that can operate at these speeds so that we can develop aircraft to cruise in this speed regime. Two such experimental aircraft currently being tested include the X-33 and the X-34. It is a tremendous challenge to design an airplane shape and an engine that can take off subsonically, accelerate through supersonic speeds, and cruise efficiently hypersonically.

What's faster than hypersonic? Hypersonic flight occurs at very high altitudes where the air is very thin. This helps reduce the drag and the heating due to friction. This thin air and high speed is part of what makes it so difficult to design an engine for these aircraft. To fly faster than hypersonic speed requires even thinner air at higher altitude. At these speeds and altitudes a vehicle is essentially outside our atmosphere and would more correctly be called a spacecraft. The space shuttle is both a spacecraft and aircraft.



## Overhead Informational Guides

- low speed



- medium speed



- high speed



- supersonic speed



- hypersonic speed

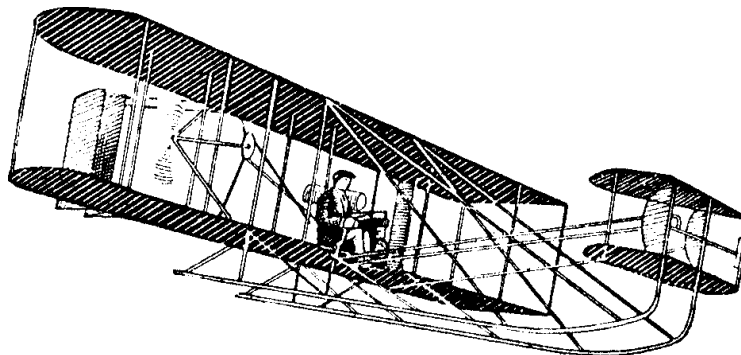




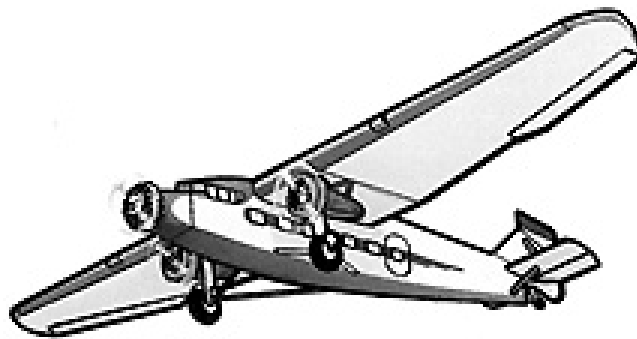
## Regimes of Flight

Low Speed (subsonic)	<ul style="list-style-type: none"><li>• 0 - 100 mph</li><li>• lightweight structures with small or no engine</li><li>• kite, balloon, hang glider, airship</li></ul>
Medium Speed (subsonic)	<ul style="list-style-type: none"><li>• 100 - 350 mph</li><li>• propeller types with straight, thick wings</li><li>• Fokker, Junkers, Cessna, Beechcraft</li></ul>
High Speed (subsonic)	<ul style="list-style-type: none"><li>• 350 - 700 mph</li><li>• powerful propeller or jet-powered engines with thin, sweepback wings and a sleek fuselage</li><li>• Boeing B-47, Vickers Viscount, Lear Jet, Sikorsky Blackhawk helicopter</li></ul>
Supersonic Speed	<ul style="list-style-type: none"><li>• 760 mph - Mach 5</li><li>• high-powered jet engines, sleek fuselage with super thin, swept-back or delta wings</li><li>• Concorde, F-15 Eagle, Stealth</li></ul>
Hypersonic Speed	<ul style="list-style-type: none"><li>• Mach 5 - Mach 10 (3,500 - 7,000 mph)</li><li>• rocket, re-entry capsules (Apollo), X-15, Space Shuttle, X-33, X-34</li><li>• high-powered rocket engines, short, thin wings, heat protection system</li></ul>

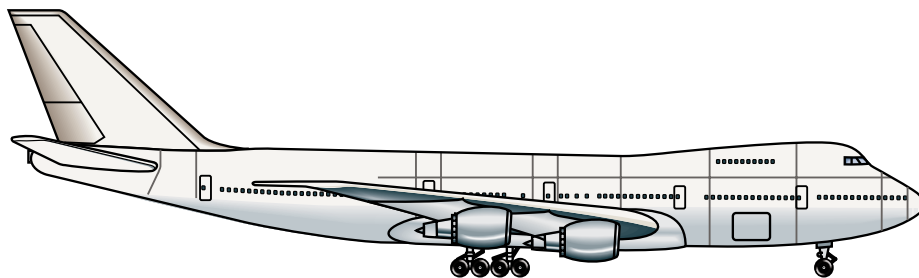
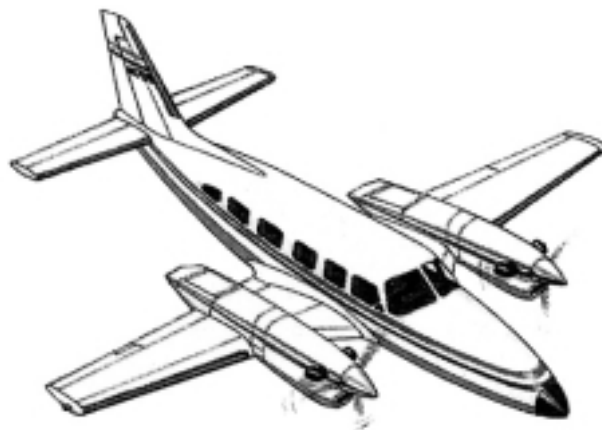
## Low Speed



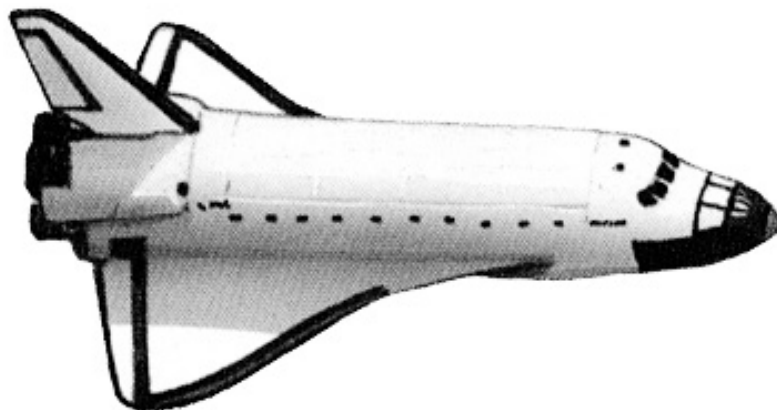
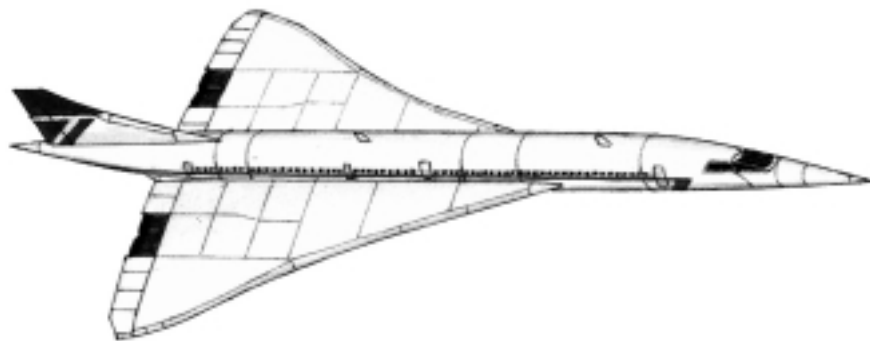
## Medium Speed



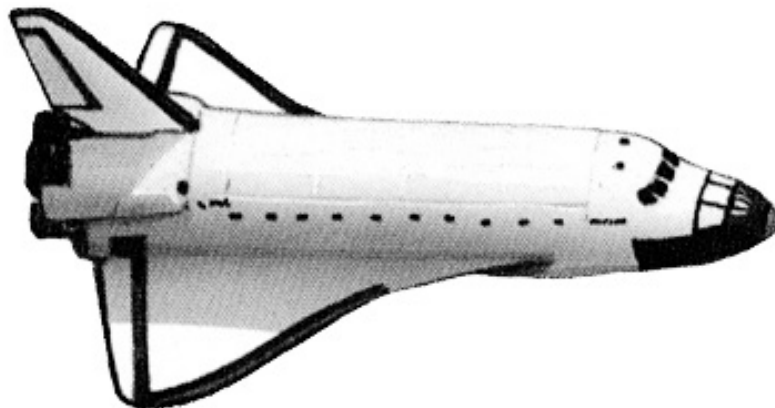
## High Speed



## Supersonic Speed

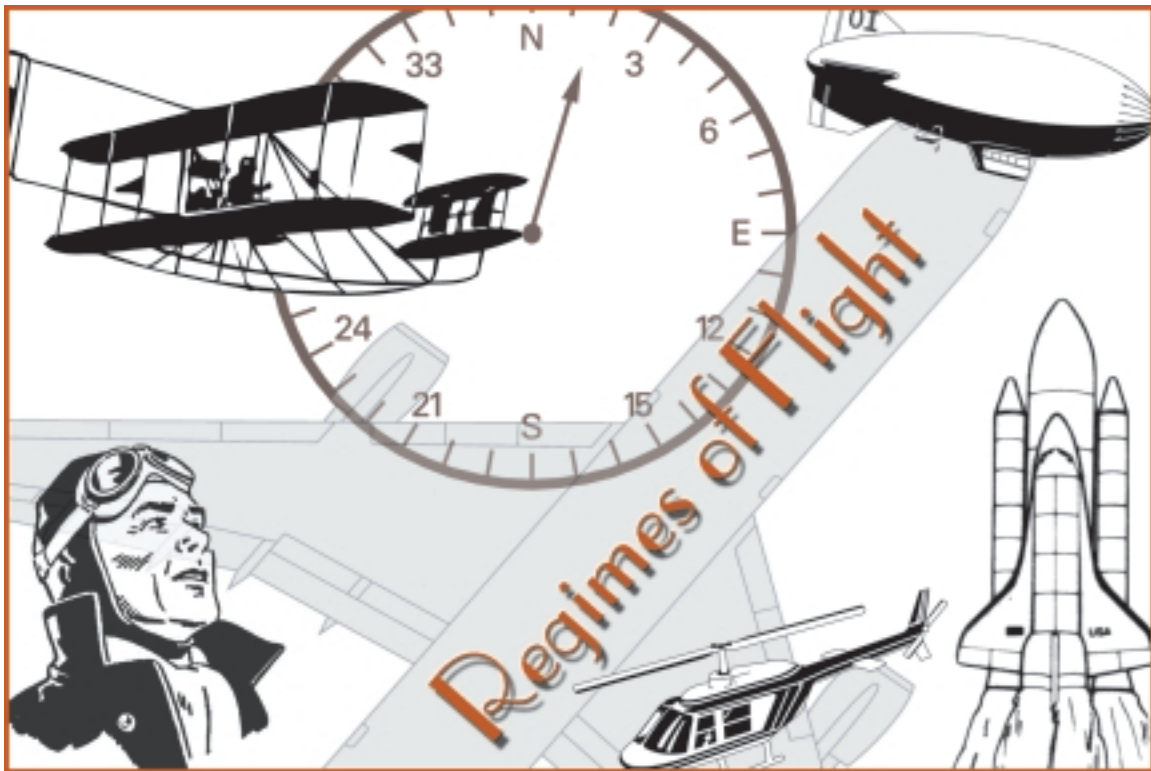


## Hypersonic Speed



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# Answer Keys



## Student Worksheet: Regimes of Flight Key

**Directions:** Match the category from the box on the right to the descriptions given on the left. Place the letter in the blank next to the proper description.

- |           |   |
|-----------|---|
| <u>M</u>  | 1. 100 - 350 mph  |
| <u>L</u>  | 2. kites, balloons, airships  |
| <u>SS</u> | 3. high-powered jet engines, sleek fuselage with super thin, swept-back or delta wings        |
| <u>H</u>  | 4. 350 - 700 mph  |
| <u>HS</u> | 5. high-powered rocket engines with thin, short wings   |
| <u>M</u>  | 6. Cessna, Fokker, Junkers  |
| <u>HS</u> | 7. Mach 5 to Mach 10  |
| <u>L</u>  | 8. lightweight structures with small or no engines  |
| <u>SS</u> | 9. greater than 760 mph, but less than Mach 5   |
| <u>M</u>  | 10. propeller types with straight, thick wings  |
| <u>HS</u> | 11. rockets, Space Shuttle, X-15  |
| <u>L</u>  | 12. 0 - 100 mph   |
| <u>H</u>  | 13. Boeing B-47, Lear Jet, Vickers Viscount   |
| <u>SS</u> | 14. Concorde, F-15, Eagle, Stealth  |
| <u>H</u>  | 15. powerful propeller or jet-powered engines with thin, sweepback wings and a sleek fuselage |

Category:
L) low speed
M) medium speed
H) high speed
SS) supersonic speed
HS) hypersonic speed

## Student Worksheet: Speed of Sound Key

**Directions:** Use the student reading “Speed of Sound” to help you answer the questions below.

1. In order for sound to move it must have a medium through which to travel. List three media through which sound travels.

*Solid, liquid, gas*

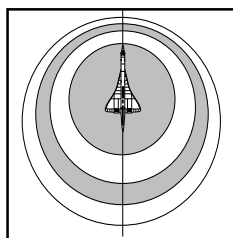
2. What is the speed of sound in miles per hour at sea level?

*760 miles per hour*

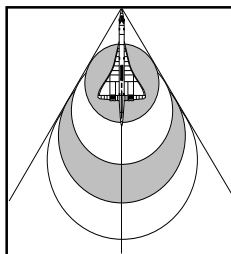
Under what conditions is this speed measured?

*Under normal atmospheric conditions*

3. Draw a picture of how sound waves coming from a subsonic aircraft move through the air at subsonic speed.



4. Draw a picture of how sound waves coming from a supersonic aircraft move through the air at supersonic speed.





# Student Worksheet: Aeronautics of the Space Shuttle

## Key

**Directions:** After reading “Aeronautics of the Space Shuttle”, answer each question below by circling the letter of the correct answer.

1. Name the vehicle that is an example of a lifting body.

- A. a Boeing 747
- B. a glider
- ☒ C. the orbiter

2. The orbiter uses what type of wing?

- ☒ A. delta wing
- B. sweepback wing
- C. straight wing

3. Which part of the space shuttle is NOT reusable?

- A. orbiter
- ☒ B. external fuel tank
- C. solid rocket booster

4. Name the “space engines” used by the orbiter to enter, exit and change orbit.

- A. solid rocket booster
- ☒ B. orbital maneuvering system
- C. reaction control system

5. Name the airplane control surface that is on the trailing edge of the orbiter’s wings.

- A. aileron
- B. rudder
- ☒ C. elevon

6. Name the engine system that is used to control the orbiter’s motions of roll, pitch and yaw while it is in the upper atmosphere.

- ☒ A. reaction control system (RCS)
- B. orbital maneuvering system (OMS)
- C. orbiter reaction system (ORS)



## Student Worksheet: Aeronautics of the Space Shuttle Key (continued)

7. What is the purpose of the S-turns during landing?

- ☐ A. to reduce heat
- ☒ B. to slow the orbiter's speed
- ☐ C. to burn extra fuel

8. The orbiter's split-rudder is used to do what?

- ☐ A. control yaw
- ☒ B. slow the orbiter
- ☐ C. both of the above

9. The orbiter lands on the runway moving at about what speed?

- ☐ A. 424 mph
- ☒ B. 215 mph
- ☐ C. Mach 1

10. One major difference between the orbiter and an airplane is found with what part?

- ☐ A. elevons
- ☒ B. wings
- ☐ C. engines

11. An elevon is a control surface that combines which two control surfaces?

- ☒ A. aileron and elevator
- ☐ B. elevator and rudder
- ☐ C. wing and aileron

12. At what speeds does the orbiter fly?

- ☐ A. hypersonic
- ☒ B. supersonic and subsonic
- ☐ C. all of the above

## Mach and Mile Mathematics with the X-15

### Exercise 1 Key

- 1:  $\frac{354,200 \text{ feet}}{5,280 \text{ feet/mile}} = 67.08 \text{ miles}$
- 2:  $354,200 \text{ feet} - 45,000 \text{ feet} = 309,200 \text{ feet}$
- 3:  $\frac{309,000 \text{ feet}}{5,280 \text{ feet/mile}} = 58.6 \text{ miles}$
- 4: answers will vary
- 5:  $4,520 \text{ miles/hour} - 4,486 \text{ miles/hour} = 34 \text{ miles/hour}$
- 6:  $\frac{4,520 \text{ miles per hour}}{65 \text{ miles per hour}} = 69.5 \text{ times faster!}$
- 7:  $762 \text{ miles/hour} - 87 \text{ miles/hour} = 675 \text{ miles/hour}$
- 8:  $\frac{4,520 \text{ miles hour}}{675 \text{ miles/hour}} = \text{Mach } 6.7$
- 9: 6.7 times the speed of sound

### Exercise 2 Key

- 1:  $\frac{65 \text{ miles/hour}}{762 \text{ miles/hour}^*} = \text{Mach } .085$   
\*from table
- 2: from table: for altitude range of 20,000 - 30,000 feet, the speed of sound in the stated air conditions is 693 miles/hour. When the pilot is flying at Mach 1, he/she is flying at the speed of sound, or 693 miles/hour.
- 3:  $762 \text{ miles/hour at sea level} - 693 \text{ miles/hour at } 29,028 \text{ feet} = 69 \text{ miles/hour}$
- 4:  $354,200 \text{ feet} - 29,028 \text{ feet} = 325,172 \text{ feet}$   
 $325,172 \text{ feet} / 5,280 \text{ feet} = 61.6 \text{ miles}$   
answers will vary
- 5:  $\frac{3,111 \text{ miles/hour}}{662 \text{ miles/hour}} = \text{Mach } 4.7$
- 6:  $\frac{15 \text{ miles per hour}}{762 \text{ miles per hour}} = \text{Mach } .02$   
That's two one-hundredths of the speed of sound!  
 $\text{Mach } .02 \times 693 \text{ miles/hour} = 13.86 \text{ miles/hour}$

## The Aspect Ratio of Wings

**Review:** As air flows over and under a wing, we know from our study of lift that the air flowing over the top flows faster than the air that flows under the wing. We also know from Bernoulli's Principle that the air that flows faster applies less pressure to the surface it is flowing over. Therefore, since the air flowing over the top of a wing has less pressure (because it is flowing faster), the air pressure on top is less than on the bottom of the wing. The higher air pressure on the bottom "lifts" the wing.

**Background:** When engineers design a new airplane, the size and shape of the wings are a very important issue. Wings provide the majority of the lift for the airplane, but they also cause drag. Remember that drag is a force that opposes the thrust force. Engineers are always trying to find ways to increase lift and reduce drag caused by the wings.

In addition to flowing faster, the air that flows over the top of the wing also tends to flow inward, toward the fuselage. The air that flows underneath the wing is flowing more slowly and tends to flow outward. As these two airflows meet along the trailing edge of the wing, they form a rotating column of air that extends from the wing tip. This is called a wing-tip vortex.

If they are lucky, passengers riding behind the wing of an airplane can sometimes see a wing-tip vortex - particularly if they are flying in the morning or on a slightly humid day. It looks like a long, slim whirlwind that extends from the tip of the wing.

Unfortunately, while they are fun to watch, the same characteristics of the airflow that create wing-tip vortices (the plural of vortex is vortices) also create drag.

## Teacher - Led Exercise

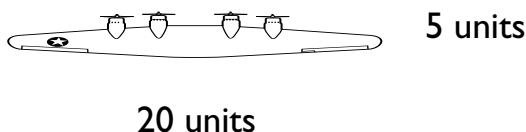
**Directions:** In their efforts to increase lift and reduce drag, engineers use a mathematical formula called the “aspect ratio”. The “aspect ratio” is simply a comparison between the length and width of the wing:

$$\frac{\text{length of the wing}}{\text{width of the wing}} = \text{aspect ratio}$$

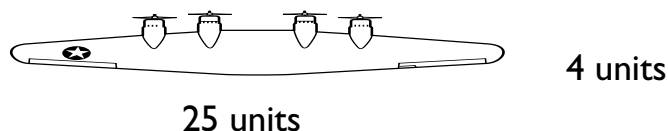
Experiments have shown that a wing built with a higher aspect ratio tends to create less drag than a wing built with a smaller aspect ratio - even when their area remains the same!

Examine the three wings drawn below, calculate the area and aspect ratio of each wing, and fill in the following table. Then, rank the wings according to the drag that each will create, given their aspect ratios. Rank the wing with the least drag, number 1 and the greatest amount of drag, number 3.

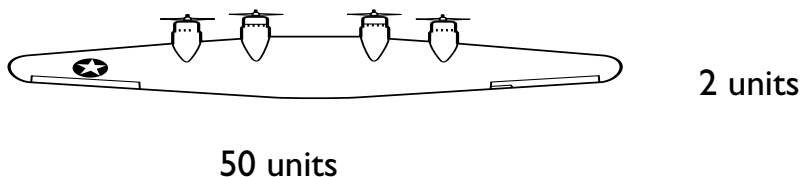
### Wing “A”



### Wing “B”



### Wing “C”



## The Aspect Ratio of Wings

### Teacher - Led Exercise Key

**Wing “A”:** *length: 20 units      width: 5 units*

**Wing “B”:** *length: 25 units      width: 4 units*

**Wing “C”:** *length: 50 units      width: 2 units*

<b>Wing</b>	<b>length</b>	<b>width</b>	<b>area</b>	<b>aspect ratio</b>	<b>drag ranking</b>
<b>A</b>	<i>20 units</i>	<i>5 units</i>	<i>100 square units</i>	<i>4</i>	<i>3</i>
<b>B</b>	<i>25 units</i>	<i>4 units</i>	<i>100 square units</i>	<i>6 R1</i>	<i>2</i>
<b>C</b>	<i>50 units</i>	<i>2 units</i>	<i>100 square units</i>	<i>25</i>	<i>1</i>

Even though each wing has the same area, 100 square units, Wing “C” has the greatest aspect ratio, and Wing “A” has the smallest aspect ratio. This implies that Wing “A” creates more drag than Wing “C”.

Maybe you’ve wondered why sailplanes and gliders have long, slim wings. Since they don’t have engines to provide thrust, their wing shape helps to provide the greatest amount of lift with the least amount of drag.

## Exercise 1 Key

**Step 1:** Possible wing dimensions and aspect ratios:

length = 9	width = 8	aspect ratio = 1 R1
length = 12	width = 6	aspect ratio = 2
length = 36	width = 2	aspect ratio = 18
length = 24	width = 3	aspect ratio = 8
length = 18	width = 4	aspect ratio = 4 R2

Wing	length	width	area	aspect ratio	drag ranking
<b>A</b>	9 units	8 units	72 square units	1 R1	2
<b>B</b>	12 units	6 units	72 square units	2	1

## Exercise 2 Key

**Step 1:** Possible wing dimensions and aspect ratios:

length = 100	width = 2	aspect ratio = 50
length = 50	width = 4	aspect ratio = 12 R2
length = 20	width = 10	aspect ratio = 2
length = 25	width = 8	aspect ratio = 3 R1

Wing	length	width	area	aspect ratio	drag ranking
<b>A</b>	100 units	2 units	200 square units	50	1
<b>B</b>	20 units	10 units	200 square units	2	2

# Experiment: Air Has Weight

## Key

Steps	Data
<p><b>1. <u>State the problem.</u></b></p> <p><b>QUESTION</b></p> <p><i>(What do I want to know?)</i></p>	<p><i>Does air have weight?</i> <i>Does air weigh anything?</i></p>
<p><b>2. <u>Form a hypothesis.</u></b></p> <p><b>PREDICTION</b></p> <p><i>(What do I think is going to happen?)</i></p>	<p><i>I think that the broken balloon will weigh less than the un-broken balloon.</i> <i>I think that they will weigh the same because air doesn't have anything in it.</i> <i>I think that the full balloon will weigh more because I know from the other experiment that air takes up space so it must weigh something too!</i></p>
<p><b>3. <u>Design an experiment.</u></b></p> <p><b>MATERIALS &amp; PROCEDURES</b></p> <p><i>(What steps will I take to do this experiment? What things will I need?)</i></p>	<p><i>Materials:</i> <i>2 equal-sized balloons (inflated with as close to an equal amount of air as possible) • string • yard/meter stick • tape • stick pin</i></p> <p><i>Procedure:</i></p> <ol style="list-style-type: none"> <li><i>1. Gather materials.</i></li> <li><i>2. Tie string to center of stick (in a horizontal position) so that the stick hangs evenly in a horizontal position.</i></li> <li><i>3. Tape a balloon to each end of the stick.</i></li> <li><i>4. Hold stick by the centered stick and observe and record.</i></li> <li><i>5. Take the straight pin and carefully puncture (pop) one balloon so as not to disintegrate it into smaller pieces.</i></li> <li><i>6. Hold stick by centered string and observe and record.</i></li> </ol>

# Experiment: Air Has Weight

## Key

### Steps

#### 4. Perform the experiment.

#### **OBSERVE and RECORD DATA**

(What information did I gather during this experiment?)

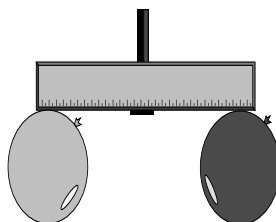
### Data

*Before the balloon was popped:*

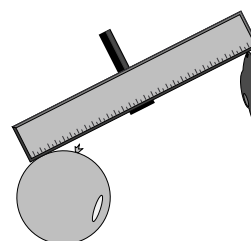
- Stick remained nearly level in horizontal position.
- After balloon was popped, that side of the stick rose.

#### 5. Organize and analyze data.

(Make a graph, chart, picture or diagram.)



nearly equal



this side is heavier

this side is lighter

#### 6. Draw conclusions.

(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)

*Because the balloon full of air caused the stick to lower at that end, it means that it was heavier there than at the popped end.*

*Because both balloons are identical and weigh the same, the unpopped balloon weighs more because it has air in it. Air, then, must have weight.*

## Experiment: Air Has Stuff in It Key

Steps	Data
<p><b>1. <u>State the problem.</u></b></p> <p><b>QUESTION</b></p> <p><i>(What do I want to know?)</i></p>	<p><i>Does air take up space?</i></p>
<p><b>2. <u>Form a hypothesis.</u></b></p> <p><b>PREDICTION</b></p> <p><i>(What do I think is going to happen?)</i></p>	<p><i>I think air will take up space in the bottle and the water will not fill up the bottle completely. Because air will keep the water out, the cloth will remain dry.</i></p> <p>OR</p> <p><i>I think that water will fill the bottle because it is empty. The cloth will get wet.</i></p>
<p><b>3. <u>Design an experiment.</u></b></p> <p><b>MATERIALS &amp; PROCEDURES</b></p> <p><i>(What steps will I take to do this experiment? What things will I need?)</i></p>	<p><i>Materials:</i> empty glass • small, dry handkerchief/cloth • basin of water</p> <p><i>Procedure:</i></p> <ol style="list-style-type: none"> <li><i>1. Collect the materials.</i></li> <li><i>2. Shake the bottle out to make sure it is completely empty.</i></li> <li><i>3. Stuff (tape) handkerchief to bottom of glass jar (so it doesn't fall or hang down).</i></li> <li><i>4. Hold the jar with its mouth perpendicular to water and quickly immerse it in water.</i></li> <li><i>5. Hold it firmly against the bottom of the basin. Observe and record.</i></li> <li><i>6. Withdraw bottle by reversing method and pull out handkerchief. Observe and record.</i></li> </ol>

## Experiment: Air Has Stuff in It Key

### Steps

#### 4. Perform the experiment.

#### **OBSERVE and RECORD DATA**

(What information did I gather during this experiment?)

### Data

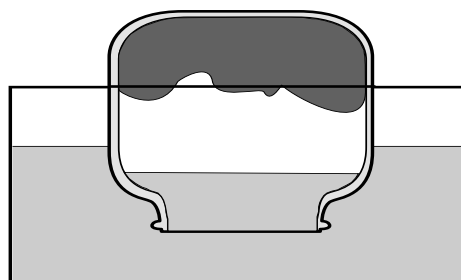
*A few bubbles came up to the surface immediately after the jar was immersed.*

*Water rose only part way (1/2, 1/3, 1/4) up into the jar and stopped.*

*Handkerchief remained dry.*

#### 5. Organize and analyze data.

(Make a graph, chart, picture or diagram.)



#### 6. Draw conclusions.

(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)

*The water only came up part way because the air took up space and kept it out. Because air has weight, air can push or has pressure.*

*This pressure keeps the water out.*

## Experiment: The Force of Thrust Key

### Steps

#### **1. State the problem.**

#### **QUESTION**

*(What do I want to know?)*

### Data

*How does thrust move an object?*

OR

*In what direction does thrust move an object?*

OR

*How does thrust work?*

#### **2. Form a hypothesis.**

#### **PREDICTION**

*(What do I think is going to happen?)*

*I think thrust will push the object forward along the line as the air comes out the back end.*

OR

*As the air inside comes out the opening of the balloon, it will push against the air outside and move the balloon forward. I think the balloon will move faster at first and then slow down as the air runs out.*

#### **3. Design an experiment.**

#### **MATERIALS & PROCEDURES**

*(What steps will I take to do this experiment? What things will I need?)*

*Materials: Soda straw • balloon (elongated)*

*Procedure:*

- 1. Gather and prepare materials.*
- 2. Inflate balloon, hold mouth closed and place on a string.*
- 3. Pull string tightly and let balloon go.*
- 4. Observe and record.*

## Experiment: The Force of Thrust

### Key

#### Steps

##### **4. Perform the experiment.**

##### **OBSERVE and RECORD DATA**

(What information did I gather during this experiment?)

##### **5. Organize and analyze data.**

(Make a graph, chart, picture or diagram.)

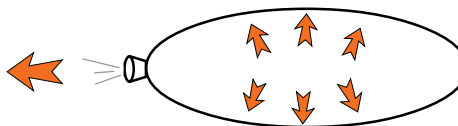
##### **6. Draw conclusions.**

(What do my results mean? Was my hypothesis right or wrong? Can I explain why?)

#### Data

*The balloon moved fast at first and then slowed down as the balloon ran out of air.*

*The air came out the back end of the balloon which pushed the balloon in the opposite direction.*



*These results mean that Newton's Third Law of Motion (which we talked about earlier) explains how thrust works. The air comes out in one direction and pushes the balloon in the opposite direction. This must be how rockets work. My hypothesis was right because I had seen this done before. I do wonder why the air comes out of the balloon — I'm not squeezing the balloon. I wonder if it has something to do with air pressure.*